

## IGFET and Tuning Circuit

### Field of the Invention

The present invention relates to an insulated gate field effect transistor and a tuning  
5 circuit.

### Background to the Invention

LC tuned circuits are widely used in RF circuits, such as oscillators and tuned  
amplifiers. It is often necessary, for instance in multiband radio equipment, to  
10 change the resonant frequency of a circuit. At HF frequencies, relays can be used to  
switch capacitors, inductors or entire tuned circuits into and out of use. However,  
at higher frequencies, relays become unsuitable. Furthermore, relays have a  
relatively high current demand and are undesirable at any frequency for this reason.

15 Subsequently, PIN diodes came to be used for RF switching, including the switching  
of capacitors and inductors into and out of tuned circuits. However, in order for a  
PIN diode switch to close, the PIN diode must be forward biased which results in a  
significant current flow.

20 The use of MOSFETs to effect switched tuning has the advantage of negligible  
current demand and has been proposed in Kral, A. *et al*, "RF-CMOS Oscillators  
with Switched Tuning", *Proceedings of the Custom Integrated Circuits Conference*, pp 555-  
558, 1998, Kuhn, W. *et al*, "A 200MHz CMOS Q-Enhanced LC Bandpass Filter",  
*IEEE Journal of Solid-state Circuits*, Vol. 31, no. 8, pp 1112-1122, August 1996 and  
25 Cho, T. *et al*, "A Single-Chip CMOS Direct-Conversion Transceiver for 900MHz  
Spread-Spectrum Digital Cordless Phones", *Proceedings of the IEEE International Solid-  
State Circuits Conference*, pp 228-229 & 464, 1999. However, the use of MOSFETs in  
this way has not become commonplace.

30 Furthermore, the known circuits are restricted to switching components in an out of  
circuit by controlling the resistance between a node, e.g. one terminal of a capacitor,  
and an AC ground, typically 0V for NMOS devices and +V for PMOS devices.

### Summary of the Invention

According to the present invention, there is provided a tuning circuit comprising a first reactance, a second reactance and a insulated gate field effect transistor having a gate arranged to receive a control signal, the first reactance being connected  
5 between the source of the field effect transistor and a first node and the second reactance having the same value as the first reactance and being connected between the drain of the field effect transistor and a second node, wherein the first and second nodes are arranged so as to experience a balanced ac signal. The field effect transistor may be a p- or n-channel device and is preferably an enhancement mode  
10 device. A balanced ac signal comprises two waveforms which are reciprocal relative to an ac ground, such as is found in a balanced transmission line.

The first and second reactances may be both either capacitors or inductors.

15 A capacitor and/or an inductor may be connected between said nodes.

According to the present invention, there is also provided an insulated gate field effect transistor comprising source and drain regions within a surrounding region and gate electrode means provided over a channel or channels between said source  
20 and drain region and over at least part of the boundary between said source and drain regions and said surrounding region, said surrounding region being provided with ground connection means for connection to an AC ground. The source and drain regions are preferably n- or n<sup>+</sup>-type within a p-type substrate region. If, however, the source and drain regions are p- or p<sup>+</sup>-type, the substrate region may be  
25 an n-type region within a greater p-type region. If the source and drain regions are n<sup>+</sup>-type the surrounding region is n- or n<sup>+</sup>-type and if the source and drain regions are p- or p<sup>+</sup>-type the surrounding region is p- or p<sup>+</sup>-type. The normalised substrate resistance of PMOS devices can be much lower than that for NMOS  
30 devices. Accordingly, when sized correctly PMOS devices can perform better than NMOS devices for switching tuning components.

The ground connection means is distinct from and in addition to the conventional substrate connection found in insulated gate field effect devices.

Preferably, the ground connection means comprises a plurality of interconnected ohmic contacts to said substrate region.

- 5    Preferably, the gate electrode means encompasses said source and drain regions.

The source and drain regions may be in a finger structure arrangement. Preferably, however, the source and drain regions are in a waffle structure arrangement.

- 10   Providing metallic interconnections between the sources and metallic interconnections between the drain regions and between the source regions of small insulated gate field effect transistor having multi-drain/multi-source topographies, e.g. the waffle structure.

- 15   Preferably, therefore the insulated gate field effect transistor includes a plurality of source and drain regions and an interconnection layer in which said source regions are connected together and said drain regions are connected together, the conductors of the interconnection layer being connected to said source and drain regions by splaying conductive paths. Splaying the connections in this way increases  
20   the spacing between the points which need to be interconnected in interconnection layer.

- Preferably, said source and drain regions are in a waffle structure arrangement. More preferably, the interconnection layer comprises a source interconnection  
25   structure and a drain interconnection structure, said structures comprising respective sets of fingers extending diagonally, with respect to said waffle structure arrangement, which are interdigitated.

- An insulated gate field effect transistor according to the present invention may be  
30   advantageously employed in a circuit according to the present invention.

A circuit according to the present invention may be employed in a resonant circuit such as an oscillator or a filter.

According to the present invention, there is further provided an insulated gate field effect transistor comprising a plurality of source and drain regions and an interconnection layer in which said source regions are connected together and said  
5 drain regions are connected together, the conductor or conductors of the interconnection layer being connected to said source and drain regions by splaying conductive paths.

Preferably, said source and drain regions are in a waffle structure arrangement.  
10 More preferably, the interconnection layer comprises a source interconnection structure and a drain interconnection structure, said structures comprising respective sets of fingers extending diagonally, with respect to said waffle structure arrangement, which are interdigitated.

#### 15 **Brief Description of the Drawings**

Figure 1 is a simplified circuit diagram of a voltage controlled variable frequency crystal oscillator;  
Figure 2 illustrates the arrangement of semiconductor regions of the switching device used in the circuit of Figure 1;  
20 Figures 3a to 3d illustrate successive metallisation layers of the device of Figure 2;  
Figure 4 is a sectional view of the device shown in Figure 2;  
Figure 5 shows the equivalent circuit of the device of Figure 2; and  
Figures 6a to 6d illustrate alternative tuning circuits.

#### 25 **Detailed Description of the Preferred Embodiments**

Embodiments of the present invention will now be described, by way of example, with reference to the accompanying drawings.

Referring to Figure 1, a voltage controlled crystal oscillator comprises a pair of  
30 transistors 1, 2, first and second current sources 3, 4 for controlling the emitter currents of the transistors 1, 2 and an active, cross-coupled load arrangement 5 providing the collector loads for transistors 1, 2. The load arrangement 5 comprises a differential amplifier 6 and third and fourth controlled current sources 7, 8

connected between the collectors of respective transistors 1, 2 and  $V_{cc}$ . The controlled current sources 7, 8 are controlled by the differential amplifier 6 whose inputs are connected to the collectors of respective transistors 1, 2.

5 The frequency determining components of the oscillator comprise a quartz crystal 9, a first capacitor 10 between the emitters of the transistors 1, 2, an n-channel depletion mode MOSFET 11, a second capacitor 12 connected between the drain of the MOSFET 11 and the emitter of the first transistor 1 and a third capacitor 13 connected between the source of the MOSFET 11 and the emitter of the second  
10 transistor 2.

Briefly stated, when a low voltage is applied to the gate of the MOSFET 11, its source-drain resistance is high and the second and third capacitors 12, 13 do not significantly effect the frequency of the oscillator. However, if a relatively high  
15 voltage is applied to the gate of the MOSFET 11, its drain-source resistance is low and the frequency of the oscillator is lowered due to the effect of the second and third capacitors 12, 13 in parallel with the first capacitor 10. Thus, a step change in the frequency of the oscillator can be achieved by changing the voltage  $V_{tune}$  on the gate of the MOSFET 11.

20 Referring to Figure 2, the MOSFET 11 has a 4 x 4 waffle structure which provides for relatively low source-drain parasitic capacitances. The first row 20 of the waffle structure consists of a first source region 21, a first drain region 22, a second source region 23 and a second drain region 24. The second row 25 of the waffle structure  
25 consists of a first drain region 26, a first source region 27, a second drain region 28 and a second source region 29. The third row 30 is the same as the first row 20 and the fourth row 31 is the same as the second row 25.

Referring also to Figures 3a to 3d and 4, the source and drain regions 21, ..., 24, 26, ..., 29 are  $n^+$  doped areas within a p-type substrate. An n-type region 33  
30 surrounding the waffle structure is connected at frequent intervals to AC ground. The gate electrode 34 comprises a polysilicon grid. In addition to overlying the channel regions between source and drain regions, the gate electrode 34 includes a

solid perimeter which overlays the gap between the outer source and drain regions 21, ..., 24, 26, 29 and the n-type region 33.

Referring particularly to Figure 3a, a first metallisation layer comprises a square  
5 interconnect ring 25, connecting vias 36 to contacts with the n-type region 33 surrounding the waffle, and pads 37 atop respective vias to source and drain regions 21, ..., 24, 26, ..., 29.

Referring particularly to Figure 3b, a second metallisation layer comprises lateral  
10 conductor paths 38a, ..., 38l radiating from the tops of vias to respective peripheral source and drain regions 21, ..., 24, 26, 29. The corner conductor paths 38a, 38d, 38i, 38l extend diagonally away from the waffle. The other conductor paths 38b, 38c, 38e, 38f, 38g, 38h, 38j, 38k extend parallel to axes of the waffle and are broadened at their outer ends the direction of the nearest corner conductor path  
15 38a, 38d, 38i, 38l. The second metallisation layer also comprises pads 39 atop vias to the pads 37 of the first metallisation layer over the other source and drain regions 27, 28.

Referring particularly to Figure 3c, a third metallisation layer comprises twelve  
20 evenly spaced pads 40 arranged to form the sides of a square, each atop a via to an outer end of one of the conductor paths 38a, ..., 38l of the second metallisation layer. The third metallisation layer also includes short diagonally radiating conductor paths 41 from the tops of vias to the pads 39 of the second metallisation layer.

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Referring particularly to Figure 3d, vias are formed from the pads 40 and the outer ends of the conductor paths 41 of the third metallisation layer. A fourth metallisation layer comprises a square array of regularly spaced pads 42 at the top of these vias, a first conductor pattern 43 interconnecting the pads 42 connected to  
30 source regions 21, 23, 27, 29 and a second conductor pattern 44 interconnecting the pads 42 connected to drain regions 22, 24, 26, 28. The first and second conductor patterns 43, 44 each comprise a set of diagonally extending fingers. The

fingers of the first conductor pattern 43 are interdigitated with those of the second conductor pattern 44.

5 The centre to centre separation of neighbouring pads 42 in the fourth metallisation layer is much greater than that of the underlying source and drain regions 21, ..., 24, 26, ..., 29 due to the radiating paths 38a, ..., 38l, 41 in the second and third metallisation layers, making formation of the first and second conductor patterns 43, 44 easier.

10 The extension of the gate electrode 34 to overlies the border between the outer source and drain regions and the surrounding n-type region has been found to have several advantageous effects, including:

- (a) reduced effective resistance to ground when the MOSFET is turned on;
- 15 (b) the drain and source regions are rapidly biased at the desired bias level when the switch is turned on;
- (c) when the MOSFET is turned off, the parasitic drain/source capacitance is reduced because the outer side walls of the outer diffusion regions have much more capacitance than the gate-side walls due to the lightly doped  
20 diffusion used in modern processes near the gate; and
- (d) the Q of the junction capacitance is improved because the distributed substrate resistance to ground has been reduced by the increased proximity and number of ground terminals.

25 The first and second conductor patterns 43, 44 can be made symmetrical by arranging for there to be an even number of rows and an odd number of columns, or vice versa, in the waffle structure.

30 While the present invention has been described above in the context of a crystal controlled oscillator, it will be appreciated that it can be used for switching both capacitors and inductors in LC circuits.

Referring to Figure 6a, the capacitor switching arrangement of Figure 1 is applied to an LC tank circuit including an inductor 51 connected in parallel with the first capacitor 10.

5 Referring to Figure 6b, the circuit of Figure 6a is modified by connecting a fourth capacitor 54 between the drain and source of the MOSFET 11. Consequently, turning on of the MOSFET 11 increases the capacitance of the tank circuit, thereby decreasing the resonant frequency of the tank circuit.

10 Referring to Figure 6c, the circuit of Figure 6a is modified by replacing the second and third capacitors 12, 13 with second and third inductors 52, 53.

Referring to Figure 6d, the circuit of Figure 6c is modified by connecting the second and third inductors 52, 53 in series and arranging to MOSFET 11 to selectively  
15 provide a short between taps on the second and third inductors 52, 53.

In a further alternative embodiment, the MOSFET 11 and the associated capacitors 12, 13 are located in parallel with the crystal 9.

20 It will be appreciated that many modifications may be made to the embodiments described above without departing from the spirit and scope of the claims appended hereto.